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# PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

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## TITLE OF THE INVENTION (280 characters max)

Optimized light source and beam shaping system and method

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## ENCLOSED APPLICATION PARTS (*check all that apply*)

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☑ Application Data Sheet. See 37 CFR 1.76

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☐ Other (specify)

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*Respectfully submitted,*

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# Provisional Application for a patent

## 17/10/2003
## Cover page

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**US Government agency that has a property interest**
None

# Contents

**Background of the invention and Abstract of Disclosure**

This invention comprises several innovative elements/methods that can be used separately or together to achieve an improvement in light source technology utilized in optical element fabrication and in projection systems.
The invention includes innovative light source technology improvements, as well as novel beam shaping elements/methods enabling total control on the light beam shape and its properties, thus enabling variety of applications for such technology.

***Light source improvements:***
As light source technology evolves, Light Emitting Diodes and Laser Light sources are being used in ever growing applications.

These types of light sources are starting to replace standard light sources such as halogen, florescent, etc, because of their increased optical efficiency and low power consumption.

The problem still keeping LEDs and lasers from becoming key light sources in the illumination/multimedia industry is the inability to provide high optical power, with relatively low power consumption, and small light source physical size with overall low price, this is also due to low efficiency of today's projection system that enforces high power sources. It is required to have innovative approaches on both the light sources aspects and the optical path (for example: beam shaping) aspect to dramatically optimize projection systems' performance, costs and size.
Other applications such as fabrication of optical elements that require low cost fabrication methods (with total control on beam properties) can also be improved.

From the light source improvement point of view, VCSEL Arrays (for example: two dimensional vertical cavity surface emitting lasers) seems as a promising light source that can be used to illuminate the optical path, since they are miniature in size and are cost efficient. Obviously, special beam shaping means would be required in order for the VCSELs to be used as an optimized light source.

Unlike the FP (Fabry-Perot -> meaning edge emitter diodes as most LDs today) cavity of an edge-emitting laser diode which is 250 to 500 um in length, the entire size of a VCSEL is limited only by the dimensions of the emitting region and space for electrical contacts. Thus, the die for a complete VCSEL can potentially be only slightly larger than the beam size! Currently available devices with a 5-25 um circular beam are about 100 um (including heat dispersion surface), but this can certainly be reduced to 50 um or less. Smaller size can translate into a larger yield per wafer and lower costs as well a higher packing density for laser array applications. FP laser diodes must be diced up (and possibly even mounted) just to determine which are good and which are bad. They cannot be tested at all when part of the original wafer since the edges haven't been cleaved yet. This is an expensive time consuming process and results in a lot of wasted effort and materials. On the other hand, an entire wafer of VCSELs can be tested as a unit with each device evaluated for lasing threshold and power, beam shape, quality, and stability. It is possible to form millions of VCSELs on a single wafer as a batch process and then test and evaluate the performance of each one automatically. The entire wafer can be burned in to eliminate infant mortalities and assure higher reliability of the final product. Each device can then be packaged or thrown away based on these findings.

Virtually the same equipment that is used for final assembly of devices like other ICs can be used for VCSELs since they are attached flat on the package substrate and shine through a window like that of an EPROM (but of higher optical quality) or merged with an optical fiber assembly as required. Since the active lasing semiconductor and mirrors are buried under the top surface layers, a hermetic seal is unnecessary. VCSELS can use inexpensive plastic packaging and/or be easily combined with other optical components as a hybrid or chip-on-board assembly. All this further contributes to reduced cost.

Nowadays most of the VCSELs work within the non visible range mostly for purposes of telecommunication.

***VCSELs with beam shaping architectures:***
By using non-linear optical (NLO) crystals along with VCSELs where they are being pumped with the VCSEL lasing light we can obtain visible beams, for example green or blue light.
This can be done through pumping and then frequency doubling or by frequency doubling alone.
2D VCSEL array (an array of micro light sources) can be fabricated to form the required optical output to pump a lasing crystal where along with special optical element (for example: micro-lens array, inverse dammann grating as described further below) forms a single light beam on the surface of the crystal.

***Optimization of crystal pumping:***
Alternatively, the VCSELs can be lit on and off in groups in different timings when each group lases over the crystal in a different location within the total lasing surface, thus allowing better dispersion of heat along the coating substrate and maintaining better reliability of the coatings over the crystal by not over heating a single spot and burning the coating.

Due to this a higher power can be driven with smaller and/or cheaper crystals.

It is also possible to use VCSELs with the given wavelength of Green, Red or Blue as illumination channels without crystal pumping as such VCSELs with these visible wavelengths were shown by UCSB Final Report 1998-99 for Project 98-034 (**Blue and Green InGaN VCSEL Technology**)

The use of innovative setups of variations of VCSEL arrays, Laser die arrays, and LEDs along with special beam shaping optics in the same projection system could potentially create great reduction in cost and physical size, higher output brightness and lower electrical power consumption.

***Special Light module:***
An innovative light module can be created by the use of pulse modulation along with light sequencing mechanism, which allows us to create an optimal light module for projection systems where a light sequential operation is required and there is no requirement for continuous light operation, for example: projection systems where R, G, B sources are sequentially lit to create a full color video image.
In such systems a maximum of 33% of the ON time is dedicated to each color source(R, G, B), thus the optimal light source would not be one which was primarily designed to work 100% of the time, but only 33% of the time.

The Light module can be composed of several light sources.
By sequencing the light sources, at any given time only one light source is being lit.
After one light source has been lit for a certain period of time, the light source is turned off, and another light source is turned on.

Since in every given moment, at least one light source in turned on, the whole light module is seen to the human eye as constantly lit for the required operation time.

The sequencing mechanism allows the light module to have smaller physical size, since heat generated by one light source is absorbed by the whole light module medium. Since every time a different light source is on, at any given time the light source that was previously on is now cooling down while other light source which is on heats up. This also enables over-current operation of the light source generating higher peak power light pulses with better electrical to optical conversion efficiency.
The light module can contain any given number of light sources in the same wavelength (for example: red), or a plurality of light sources in different wavelengths.

An example of a light module can be a 2D addressable VCSEL array where we can drive groups of VCSELs for very short time periods to cover the max 33% of the total color illumination. by doing so we can squeeze more optical output from the VCSELs as so we can have each VCSELs group to be lit for a duty cycle of 5% and be turned off 95% of the time, while other groups of VCSELs cover the off time of the first group till filling the entire 95% off time of the first group and then the first VCSELs group is lit on again in a repetitive manner.
The VCSELs group has then time to cool off but they can deliver higher peak power when they are being lit in short times than if they were to be on in CW. Thus, the light module's total output optical power for a duty cycle of 33% would be higher with relatively lower electrical power consumption in comparison to a high power CW light source that would have been used only for 33% of the time. Therefore power consumption is optimized.

Same method can be formed and used in other illumination sources that can be combined with 2D VCSEL pumping array, for example LED dies, a group of LEDs can be lit a total of maximum 33% of the time, for its given color sequential operation, where individually each die is lit only about 5% of the 33% time and being off about 95% of the 33% time.
The optical output can rise up by as much as a factor of 15 within such usage with LEDs if the total timing will not exceed above 5ms of timing cycle. Since color sequential within projection displays requires at least 180 Hz of frame rate operation then reaching 5ms is not something that will serve as a limit or an obstacle.

Also, using laser dies array, for example as RED illumination source; same method can take place thus reaching similar results.

***Polarization and Speckle reduction:***
VCSEL array source and laser die array source both can deliver polarized output beam thus improving transmittance of light through the spatial light modulator and optical path with less heat dispersion, allowing total physical system shrinkage to take place.

Illuminating with either VCSEL array source and/or laser die array source in such a way (As presented above) will also cause different patterns of speckles to be formed and appear on each cycle and due to that will cause speckle reduction on the output image and maintain a clear speckle free image.
Since VCSELs are typically being used in telecommunication applications, even faster switching of the lasers is possible (up to millions of cycles per second), further reducing the speckle phenomena as speckles pattern keep changing each ON cycle.

***Beam Shaping:***

The above paragraphs detailed numerous improvements in light source technology. The following paragraphs detail innovative beam shaping elements/methods that can be used to dramatically optimize/improve projection systems.
Aside from projection systems, the beam shaping elements/methods can be used to improve other applications/systems such as optical elements fabrication.

Some beam shaping elements/methods can be used, for example, to dramatically improve the efficiency of light impinging over an SLM's clear aperture as will be detailed further below. A brief background will be presented first, in order to show the need for such elements/methods:

Spatial light modulators (SLM's) are commonly used nowadays as miniaturized displays (typically with a screen size of less than 1.5" diagonal) in data projectors, head mounted displays, and in the traditional viewfinders of digital cameras.
Manufacturers of SLM's seek to reduce the SLM's physical size within each generation of modulators, in order to extract new varieties of products. Yet, SLM's transmittance efficiency remains problematic and serves as a major obstacle for further shrinking the modulators in a dramatic manner, as their inner black matrix TFT mask blocks a large portion of the incoming projected light, thus forcing the use of high brightness illumination sources, to achieve an adequate output projection image. Furthermore, the portion of light blocked by the SLM derives a requirement for an SLM with a larger surface, in order to spread the accumulated heat over the SLM, as the Liquid crystal substance behavior may produce aberrations on the projected image, due to overheating. All these factors are forcing to have a relatively large SLM to allow better light transmittance and heat dispersion.

***Dammann gratings (with or without lenslet arrays), multi-pixel diffractive optical phase mask (filter) and a fractal approach for beam shaping will now be disclosed:***

All these beam shaping elements/methods, when lit with a light source, can be designed to output a 2-D array of spots with equal energetic distribution.
Such beam shaping methods can be used, for example, on a coherent illumination source to be split into an NxM array of miniature beamlets/spots to fit to illuminate a plurality of SLM pixels, where each pixel on an image modulation element is being individually illuminated, as if there were NxM miniature light sources formed, each attached to its own SLM pixel. Thus, the effectiveness of the light used for illuminating out an image from an SLM is maximal, without being blocked by the SLM black matrix TFTs, moreover, avoiding having the SLM heated up and loosing large portion of the light (brightness). Also, less powerful and more miniature light sources can be used.

This novel illumination approach also delivers a unified brightness over the projected image since each pixel is individually lit and the spread of brightness across the image is 100% unified.

Using such beam shaping elements along with the illumination sources as used for projection displays, allows reducing SLM's physical size tremendously and opens up vast variety of new applications for display projection technology.
An example of another novel application which can use the 2D array of spots is a micro-lens array fabrication process, such as surface relief, where the 2D array of spots in illuminated with UV light, generating a 2D array of UV spots. The UV light spots impinging on a photo-resist material generate a pattern with intensity distribution having lenslet (micro-lens array) like profile. This fabrication approach could potentially reduce manufacturing

cost and enable the creation of new types of features/patterns other then lenses.

***Various Dammann gratings will now be presented as beam shaping elements/methods:***

**Dammann gratings** are an analytical approach for realizing a desired spot distribution at Fourier plane by using a binary phase only gratings. The transition points between –1 to 1 transparency value are computed by solving equations set yielding the required spot structure. Dammann gratings are a periodic structure having a symmetric basic period, meaning they are binary diffractive optic element (DOE) gratings, having several diffraction orders of equal intensity.

Illuminating a Dammann grating with a single light beam/spot can be designed to generate a 2D array of spots with equal energetic distribution (this approach might be used for generating any desired spot distribution at the Fourier plane). This 2D array of spots can be used, for example, as the illumination source of a spatial light modulator in a very optimized way (as described above).

***Multi-pixel diffractive optical phase mask (filter):***
Although Dammann gratings can generate good 2D array of spots, more promising beam shaping methods/elements are presented below, as the multi-pixel diffractive optical phase mask (filter) and the fractal approach for beam shaping.

Multi-pixel diffractive optical phase mask (filter) is an analytical solution for a phase only filter, extracting uniform 2-D array of spots.

The improved performance of this type of DOE (diffractive optical element) is obtained by applying mathematical constraints dealing with equal energetic content in each one of the spots in the array, rather than having uniformity in shape of each spot. Such energetic condition is applicable, for example, in cases where the generated 2-D array aims to illuminate a 2-D array of pixels of a spatial light modulator (SLM).
The 2D array of light beamlets then impinges individually on every pixel of the SLM thus improving efficiency.
For example, an SLM with a resolution of 1024x768 active pixels will have sets of 1024x768 beamlets individually to each pixel.
By doing so, we avoid degradation of light from the TFT mask of the SLM and dispersion of light on inactive surfaces/areas.

***Fractal approach for beam shaping:***
The multi-pixel diffractive optical phase mask (filter) element described above can be used for extracting the phase mask required to generate medium size array of spots. In order to expand this realization for large dimension arrays a fractal based approach should be used and an appropriate DOE element is created.
Assuming that the phase mask originally generated for the multi-pixel diffractive optical phase mask element is an NxN array of spots at its Fourier plane (output plane).
If the mask is expanded (scaled) by a factor of N, the NxN array will shrink by a factor of N.
Thus, if a convolution between the original and the scaled array of spots is preformed in the output plane (the Fourier plane), an array of $N^2$ by $N^2$ of spots is to be realized due to the property of the delta function that a convolution between any function and a delta function will shift the function to the position of the delta.
The convolution operation performed in the output plane is equivalent to a multiplication operation in the phase mask plane since a Fourier relation exists between the two planes.

Multiplication of two-phase masks means addition of the two phases.
In the general case one obtains equation for the phase, equivalent to the fractal equations, i.e. a structure that is composed out of a summation of the scaled versions of the same structure.
Thus, a beam shaping element can be created, generating large dimensions 2D array of spots.

***Inverse Dammann element:***
Another innovative beam shaping approach is the use of an array of light sources together with an Inverse Dammann element.
An Inverse Dammann is a Dammann gratings element, where the input (light entrance) and output (light exit) are reversed.
The purpose of the Inverse Dammann element is to turn an array of spots into a single light beam/spot.
For example, an Inverse Dammann element can turn a 2D array of VCSEL spots into a single light beam/spot, used to pump an NLO crystal (lasing/doubling crystal), creating an optimized pumping light source (as described above in the light source improvements paragraphs).

The Use of mixed sources combination (coherent and non coherent, polarized and non polarized), comprising different types of illumination sources (VCSELs, LEDS, Laser dies), along with their special beam shaping optics (Dammann, Inverse dammann, Dammann-Lenslet, multi-pixel diffractive optical phase mask, fractal beam shaping) can improve and optimize projection systems and can be used as an illumination source for other applications (for example: lenslet fabrication) with significant improvement over the state of the art, and thus, is claimed as an invention.

The combination of several light sources in a single medium, along with fast pulse mode drive operation to obtain lower consumption, higher output optical intensity and speckle reduction, with sets of light groups (Laser die Arrays, LED die arrays, VCSEL arrays) and a sequencing mechanism into a single light module is a significant improvement over the state of the art, and is claimed as an invention.

## Brief description of the drawings

In order to understand the invention and to see how it may be carried out in practice, preferred embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Figs. 1, 2,3,4,5,6,7,8 and 9 are schematically illustrating innovative elements/methods that can be used separately or implemented together.

## Detailed description of the drawings

Fig 1A:
Schematically illustrates an innovative light source module built form a plurality of micro light sources all on a single substrate. The light source 2 consists of a collection lens 4 over the plurality of micro sources 6 made out of N sources, the collection lens collects the light and directs it outwards in a parallel manner relatively unified.
The light sources 6 are lit for short period of time per source in a manner that each time the most distant source is lit in a relative manner to the one which was lit before it in order to reduce over heating in a single area of the light source module.

Fig 1B:

Schematically illustrates a rear view of one possible variant of the light source module where the module consists an internal logic unit which automatically synchronizes and controls which of the internal micro light sources is to be lit and turned off.

Light module 8 is shown in its rear view where two input power pins 10 are to be delivered with the required input voltage while the rest of the light source on and off operation is done automatically by the internal logic unit.

Fig 1C:
Schematically illustrates another possible variant of the same source where the sequencing logic unit is not present internally and on its rear side view the module 12 there are N+1 pins relatively to the number of the micro light sources that are present within the module (plus a common connection pin).
An external operating driver is required in order to operate the module correctly.

It should be noted that the light sources can be LEDs, Lasers or any combination of the two (including polarized sources types, pulsed or continuous wave types)

It should be noted that the light sources driver can also be externally utilized in the case where the sequencing mechanism is externally utilized.

It should be noted that additional optics can be added before and after the collection lens (such as top-hat diffractive elements).

It should be noted that the ON time of each micro light source within the light source module and the selectivity of which of the sources will be lit according to their internal location can be selected and controlled according to the application and the desired method of operating the light module.

It should be noted that the numbers of micro light sources and their set of arrangement within the module is not limited.

Fig 2:

Schematically illustrates a possible none limiting example of implementation of the light module where a driving signal 16 is delivered to the light sequential mechanism 18 whose main purpose is to control on which micro source is to be lit and in what portion of the time.
The light sequential mechanism 18 delivers a signal to the light driver 20 which then physically operates the designated micro light source within the array of micro light sources 22, the light which is being projected outward of the module is then collected by a collection lens 24 to uniformly project the light outwards in a parallel manner.

Fig 3A:
Schematically illustrates an Inverse Dammann optical element, demonstrating the conversion of an array of incoming low intensity light beams into a single high intensity light beam. Light sources 28 project beams 30 towards lens 32 where they are being converted by an Inverse Dammann grating element 34 into a plane wave (a single light beam) 38.
The presented structure can be used, for example, within a projection system with VCSELs groups/arrays to pump an NLO crystal in order to form a visible range wavelength illumination source, where the beamslets of the VCSELs group are translated by this optical element into a single light spot on the NLO crystal active pumping area (as further demonstrated in Figure 4).

It should be noted that the array of light sources can have any type of arrangement, any number of light source and a variety of light sources types (Lasers: VCSELs, laser dies ;LEDs).

Fig 3B:
Schematically illustrates an improved light source architecture where a diffractive optical element is being used to convert a single light beam into a 2D array of beamlets. The optical element which can be used is a Dammann grating element, though in order to form beamlets arrays greater than 11x11, a Dammann element won't be optimal as there is much energy degradation taking place. In such cases there are 2 possible architectures, the first is by using several Dammann gratings, where each spot of the first Dammann is fed to a second cascaded Dammann element individually, multiplying the number of spots of the first Dammann.
The second architecture is by using a special multi-pixel diffractive phase mask element, set to fit to beamlets size requirements and pitch size requirements as so to be capable to light the desired output plane/surface in an optimized manner. In cases where large arrays are needed, the multi-pixel diffractive phase mask element might not be effective, and a fractal beam shaping element should be used.
Light source 40 beams over the beam shaping element 42 (Dammann, phase mask element, fractal beam shaping element), where the light is converted into a 2D array of beamlets 46. The mask of beamlets was custom designed to the desired sizes of beamlets' diameter and gap of pitch. The array of beamlets 46 lights an output plane 44, where plane 44 can be any desired plane requiring illumination (for example: a photo-resistive material illuminated to generate a patterned array structure, or an SLM clear aperture area where the mask was designed to be a perfect fit with relative pixel sizes on the SLM as to maximize light efficiency through the SLM with minimum blocking).

It should be noted that the light source illuminating the beam shaping element can be of any type (Laser, LED).

Fig 4:
Schematically illustrates a novel and optimized illumination architecture supported with special diffractive means (Inverse Dammann as described in Figure 3). Light source 48 is a non visible laser array (laser dies or VCSELs), beams out a 2D array of beamlets 50 (where the 2D form of the beamlets is illustrated in 52). Beamlets 50 are collimated by lens 54 and directed towards diffractive optical element 56 where they are being converted into a single spot (illustrated in 58) to be aimed at a lasing or doubling crystal's active aperture 60 and being converted to a visible beam (illustrated in 62). The visible beam is then directed towards another diffractive optical element (top hat) 64 where its Gaussian nature is turned into a unified form to reach a total unified brightness distribution across the beam (illustrated in 66). The unified beam can be used to illuminate any surface, such as an SLM, thus having a clear and unified brightness with equal light distribution across the active surface.

It should be noted that although an NLO crystal was demonstrated, different variations of the architecture are possible with laser sources not requiring an NLO crystal at all.

It should be noted that although a single spot was demonstrated on the surface of the NLO crystal, a different type of optical element (for example: lenslet array) can be used instead of the Inverse Dammann element, to generate several spots of light on the surface of the crystal (as shown in Figure 5).

Fig 5:
Schematically illustrates a crystal as used in the illumination architectures presented in this document (for example in Figure 4), showing crystal 68 and spots of light 70, where each spot is in different location on the lasing surface, and preferably each spot turns on in different periods of time by a different set of grouped lasers (laser dies or VCSELs), thus allowing better heat dispersion over the surface of the crystal (reducing any probability to damage the coatings) and better optimization of the output optical intensity.

Fig 6:
Schematically illustrates a projection system architecture, combining two sets of 2D VCSEL sources with a 2D laser die array source within the system, along with special beam shaping optics.

Light sources 72 and 74 are both non-visible range 2D VCSEL arrays (for example 1060nm and 940nm). Light source 76 is a set of laser die array 76 (for example, 650nm range).
Micro lenslet array setup 78, 80, 82 are aligned for all the sources respectively, micro lenslet arrays setups 78, 80 which are used with 2D VCSELs sources 72, 74 are used to focus sets of VCSELs groups within the total VCSELs array to form few focused spots on the pumped crystal (preferably at different sets of times) as described in figures 4, 5.
The grouped spots exiting the micro-lenslet arrays 78 and 80 impinge on crystals 84 and 86, (for example KTP, BBO) to achieve a second harmonic generation effect thus to obtain Green and Blue light beams according to the example.
The visible beams are then directed toward multi-pixel diffractive optical phase masks (diffractive optical elements) 88 and 90 where they are converted to plurality of NxM beams as required according to the SLM's 94 pixel resolution.

Micro lenslet array 82 is made of KxL array of micro lenses according to the laser die array size, NxM (die) = KxL (lenslets) That is in order to unify the beamlets on the SLM active surface.

The beamlets from multi-pixel phase masks 88 and 90 and from lenslet 82 are directed towards periscope 92 and then towards SLM 94 In order to cover its active surface in an optimal manner. The light is then modulated and directed towards imaging lens 96 where it is magnified and projected outwards.

It should be noted that although a combination of 2 VCSELs arrays and laser die array were used, an all laser die arrays or VCSELs arrays architecture is also possible.

It should be noted that although lenslet arrays were used, diffractive optical elements (Inverse Dammann) can be used instead (optionally together with a top-hat element to equally unify the output spot's brightness).

It should be noted that although generating a few spots on the surface of the NLO crystal is preferable, a configuration where a single light spot impinges onto the NLO crystal can also be used.

It should be noted that although multi-pixel phase masks were used to provide optimal light to the SLM, other possibilities are available (such as Top-Hat, fractal beam shaping element).

It should be noted that crystals are not needed if a VCSEL in the visible wavelength range is used.

It should be noted that although it is preferable to use only a doubling crystal (for example: KTP), in some situations a lasing crystal would also be needed (for example: a setup consisting of

2D VCSEL array at 808nm would require a lasing crystal such as YVO4 and a KTP crystal to obtain Green output at 532nm).

Fig 7:
Schematically illustrates a projection system architecture, combining one set of 2D VCSEL's array with LED light source and a set of 2D laser die array within the system, along with special beam shaping optics.
2D VCSELs array 98 and 2D laser die array 102 beams through the sets of micro lenslet arrays 104 and 108 respectively.

Of which array 104 is used to focus sets of VCSELs groups within the total 2D VCSELs array to form few focused spots on the pumped crystal 110 (for example: KTP) (preferably at different sets of times) as described in figures 4, 5.

Micro lenslet array 108 is made of KxL array of micro lenses according to the laser die array size, NxM (die) = KxL (lenslets) That is in order to unify the beamlets on the SLM active surface.

Light source 100 is a LED source. Its light is collected by collection lens 106 and then directed to a diffractive optical element (top-hat) 114 where it is being reshaped from Gaussian light to rectangular unified beam, in order to improve light unification over the SLM's surface and obtaining a unified image. The light exiting from the diffractive element 114 is directed towards periscope 116.
The light which exits the pumped crystal 110 is directed to a multi-pixel diffractive optical phase mask 112, and converted to plurality of NxM beams as required according to the SLM's 118 pixel resolution and directed towards periscope 116 and from there to SLM 118.
The light which exits from lenslet array 108 is also directed towards periscope 116 where it is then directed to SLM 118.

The lights which impinge on the SLM are modulated to form an image and then projected outwards by imaging lens 120.

It should be noted that although lenslet arrays were used, diffractive optical elements (Inverse Dammann) can be used instead (optionally together with a top-hat element to equally unify the output spot's brightness).

It should be noted that although generating a few spots on the surface of the NLO crystal is preferable, a configuration where a single light spot impinges onto the NLO crystal can also be used.

It should be noted that although multi-pixel phase masks were used to provide optimal light to the SLM, other possibilities are available (such as Top-Hat, fractal beam shaping element).

It should be noted that crystals are not needed if a VCSEL in the visible wavelength range is used.

It should be noted that although it is preferable to use only a doubling crystal (for example: KTP), in some situations a lasing crystal would also be needed (for example: a setup consisting of 2D VCSEL array at 808nm would require a lasing crystal such as YVO4 and a KTP crystal to obtain Green output at 532nm).

It should be noted that although a single LED was used, an array of LED dies along with their required optics (lenslet array or a collimation lens) can be used instead (in this case the top-hat element is optional).

It should be noted that although a laser die array together with VCSEL array was used, a 2xVCSEL array or 2 laser die array configuration (along with special beam shaping optics) can be used instead.

Fig 8A:
Schematically illustrates an illumination setup consisting 2D VCSELs array together with special beam shaping means for maximum optimization to be used, for example, in the context of a projection system.
2D VCSEL's array 122 is projecting an array of beamlets 124 towards lens 126 (can serve as a plane of 2D lenslet array), where beams 128 are being collimated and forwarded towards beam shaping element 130, which is a multi-pixel diffractive optical phase mask, designed to generate an output of NxM beamlets. Beam shaping element 130 can be created from a number of phase mask elements, where each multi-pixel phase mask element is aligned individually to a specific beamlet of the VCSEL's array. That way, each VCSEL beamlet is transformed by its individual phase mask into an array of beamlets, meaning all the VCSEL's beamlets are together transformed into a large number of output beamlets 132 by all the phase masks.
The masks output optical characteristics such as pitch and size can be predetermined according to requirements of illumination.
If the number of beamlets 132 in not sufficient a second iteration can be preformed, where beams 132 are directed towards lens 134 (can also be a set of 2D lenslet array) where they are collimated and projected towards another multi-pixel phase mask 138 (can be a number of multi-pixel phase masks) to multiply the number of 2D beamlet array size achieved by the previous mask, thus achieving a large scale beamlets array.

A convolution is formed between the Fourier of the beam shaping elements to the VCSELs set and the distance of the beamlets spots may be set to be equal to the size of the array of VCSELs.
The beamlets 140 are then directed towards the desired illumination plane, for example, to illuminate a photo-resist for patterned array of optical elements fabrication, or an SLM in a fully optimized way, where each beamlet individually impinges on a corresponding pixel in the active surface of the SLM.

It should be noted that although multi-pixel phase masks were used to provide optimal light to an SLM, fractal beam shaping elements can be used instead to achieve even a larger 2D beamlets array.

It should be noted that although VCSEL's array was demonstrated, a laser die array can possibly be used instead.

Fig 8B:
Schematically illustrates an illumination setup comprising a 2D beamlet array illumination source (such as 2D array of VCSELs/laser dies), along with special beam shaping optics. Illumination source 142 is projecting an array of beamlets 144 towards lenslet array 146, where they are being collimated. The lenslet array 146 outputs an array of beamlets 148 towards beam shaping element 150 (a multi-pixel diffractive optical phase mask). Element 150 is formed of a number of sub elements (a number of phase masks), where each phase mask is individually aligned with a specific beamlet of the beamlets array 148, forming a large number of predetermined output beamlets, thus forming an array 152 of NxM beamlets with a specific size and gap between each beam according to the requirements and the multi-pixel phase sub-masks design.

It should be noted that although multi-pixel phase masks were used to create large beamlets array, fractal beam shaping elements can be used instead to achieve even a larger 2D beamlets array.

It should be noted that although VCSEL's array was demonstrated, a laser die array can possibly be used instead.

Fig 9:
Schematically illustrates an illumination setup designed to be used in the fabrication of micro structures, such as an MLA structure (micro lenslet array) as surface relief patterns.
Basically, a UV light source attached with special beam shaping optics (multi-pixel diffractive optical phase mask) is converted to an NxM array of micro UV beams with specific beam diameter and pitch size. The array of micro UV beams can be used as the illumination light source, for example as the source for photolithography processes.

Light source 154 is a 2D array of micro UV light sources (for example: VCSELs, laser dies). Source 154 projects beams 156 on a multi-pixel diffractive optical phase mask 158 (can be built out of sub-masks, mask per beamlet, as described in Figure 8A), where they are being transformed into an array of NxM beams 160 in a desired size. The array of beams 160 are then projected as the output illumination light.
For example, beam 160 can be projected onto a photo-resist (possibly polymer) coated substrate 162 (possibly glass), causing the photo-resist material to be removed where the UV light impinges (or the opposite in the case of a negative photo-resist). Since beam 160 contains an array of spots with Gaussian distribution of light, they form a matrix like shape on the photo-resist substrate making a lens like shape, thus manufacturing the basic pattern for creating micro lens arrays.

It is also possible to use a single source instead of an array of micro light sources and to design a special multi-pixel diffractive optical phase mask accordingly, to reach the same results of an array of beamlets with predetermined size.

The use of this illumination source could possibly eliminate the need for the creation of a fabrication mask, since the light source already contains the desired UV fabrication pattern, reducing the cost of the fabrication of elements such as lenslet arrays.

It should be noted that although multi-pixel phase masks were used to create large beamlets array, fractal beam shaping elements or Dammann elements can be used instead to generate the 2D beamlets array (as described in previous figures).

The following statements relate to all figures:

It should be noted that other standard optics known to the art (for example: Lens) can be added before and after the beam shaping elements for adjustment purposes only.

It should be noted that every one of the light sources mentioned in the above figures can be designed using the light module architecture, where several light sources are used, together with sequencing mechanism and pulse mode operation (as previously described in figures 1-3).

Fig 10:
Schematically illustrates a full 2D addressable VCSEL pumped based architecture consisting of three separated illumination paths supported by 2D VCSEL arrays where all paths are aimed towards a deflection mirror which scans an output image, the image is built from a set of 2D addressable channels per VCSEL illumination source where each such setup is controlled to set different patterns of gray levels and synchronically scanned by the deflection element which can be a digital micro mirror based element forming a moving square shape pattern on the projection surface with gray levels changing thus obtaining an image.
Illumination sources 164, 166, 168 are 2D VCSEL sources with different set of wavelengths, source 164 represents a 2D addressable VCSEL array at a given wavelength of 1060nm.
Source 166 represent a different illumination channel based on a 2D addressable VCSEL setup array at a different given wavelength of 860nm,
And third illumination source 168 is a 2D addressable VCSEL array at a given wavelength range of 650nm.
Source 168 acts as the RED light source of the system where the other two sources are used with crystal doubling elements to obtain GREEN and BLUE (164 used for Green, 166 used for Blue).
Source 164 beams towards doubling crystal 170 possibly KTP and converts the 1060nm IR beam it originally emitted to a 532nm Green output from the KTP crystal 170.
Source 166 beams towards a doubling crystal 172 possibly BBO which converts the 860nm IR beam from the source to 430nm Blue output from the BBO crystal 172.
The sets of beamlets in each of the sources are controlled and their brightness in determined in correspondence to the required projected image gray level per color, the IR beams consisting of the brightness pattern are projected in parallel on the doubling crystals and are interpreted into same patterns of brightness in the

doubling output side but in a different wavelength within the visible range.
Beams which are forwarded from crystals 170 and 172 and from the RED 2D addressable VCSEL setup 168 are all aimed into periscope 174 where they are being combined and are then directed towards mirror 176 and from there towards rotating mirror 178. Rotating mirror 178 does all the output scanning to create an entire image from numerous arrays of beamlets. The full output image is finally projected out through image lens 180.

It should be noted that other types of crystals (lasing and doubling) may be used to achieve the same outcome.

It should be noted that additional optical elements (for example: micro-lens array) can be added within the illumination channels.

It should be noted that the imaging lens is not mandatory.
It should be noted that although specific wavelengths of illumination VCSELs were presented to obtain colorful images, other illumination sources with different wavelengths within the non visible range can be used.

Fig 11:
Schematically illustrates a full 2D addressable VCSEL pumped based architecture consisting of one 2D addressable VCSEL array to obtain three color channels to achieve a colorful projected image.
2D addressable VCSEL array 182 is an IR illumination source at a given wavelength of 808nm which is then being split to three beams through beam splitters 184 and 186.
The lights which go out of beam splitter 184 and out of beam splitter 186 and the light which is being reflected of mirror 188 are all aimed towards liquid crystal cells 190,192,194 respectively. Each liquid crystal cell can be controlled to allow each projection

channel to be operated or to be turned off (to allow color sequential operation).

The lights which are beamed out of the liquid crystal cells 190, 192, 194 are forwarded toward lasing crystals 196, 198, 200 respectively where the wavelength per channel is converted from 808nm to a different wavelength range.
The light which is forwarded form LC 190 is beamed at lasing crystal 196 (possibly Nd: YVO4) to convert the wavelength to 1064nm and is then forwarded to a doubling crystal 206 (possibly KTP) where second harmonic generation of the light is formed and emits a visible beam at the range of 532nm (green).

Same process takes place with the light which is beamed out of LC cell 192. The light hits a lasing crystal 198 (possibly Nd:YVO4) which converts the 808nm input to 914nm and is then aimed at a doubling crystal 204 (possibly BBO) which emits a second harmonic generation of the input, thus achieving 457nm output (Blue).
At the 3rd channel the light which is beamed out of the LC 194 is directed towards a lasing crystal 200 (possibly Nd:Yag) which emits an output wavelength of 1319nm and is then directed towards a doubling crystal 202 to obtain a second harmonic generation in its output, thus achieving a 660nm output (Red).
All channels are lit in different timings in color sequential mode, where at each illumination cycle a different pattern is lit on the 808nm VCSEL array, the beams are beamed towards each channel in a parallel manner, but the patterns of that cycle are forwarded only to the channel of the corresponding color, and are blocked by the Liquid crystals in the other channels.
The light generated in each one of the channels is directed outwards as visible range patterns and projected towards periscope 208 where the light from all channels is pointed towards mirror 210 and then towards a deflection mirror 212.

Deflection mirror 212 does all the output scanning to create an entire image from numerous arrays of beamlet patterns. The full output image is finally projected out through image lens 214.

At each given cycle a control unit carefully adjusts the gray level of the 2D VCSEL array according to the inserted image feed per color and is scanned by the deflector outwards to obtain a large image out of a relatively small array of 2D VCSELs.

It should be noted that other types of crystals (lasing and doubling) may be used to achieve the same outcome.

It should be noted that additional optical elements (for example: micro-lens array) can be added within the illumination channels.

It should be noted that the imaging lens is not mandatory.

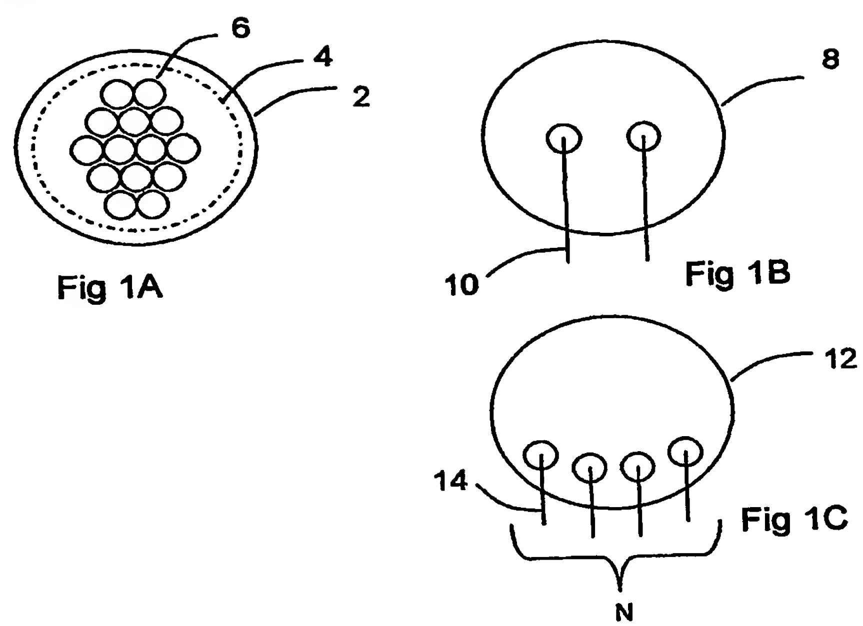
It should be noted that instead of splitting the 808nm VCSEL array into 3 channels, three 808nm VCSEL arrays can be used, each in a different channel, eliminating the need for beam splitters and liquid crystals. Alternately, a larger 808nm 2D addressable VCSEL array can be used to cover all three channels (instead of three VCSEL arrays) and illuminate each channel by controlling the VCSEL array address lines.

It should be noted that although specific wavelengths of illumination VCSELs were presented to obtain colorful images, other illumination sources with different wavelengths within the non visible range can be used.

A convolution is formed between the Fourier of the beam shaping elements to the VCSELs set and the distance of the beamlets spots may be set to be equal to the size of the array of VCSELs.
The beamlets 140 are then directed towards the desired illumination plane, for example, to illuminate a photo-resist for patterned array of optical elements fabrication, or an SLM in a fully optimized way, where each beamlet individually impinges on a corresponding pixel in the active surface of the SLM.

## Drawings

## Figure 1




## Figure 2

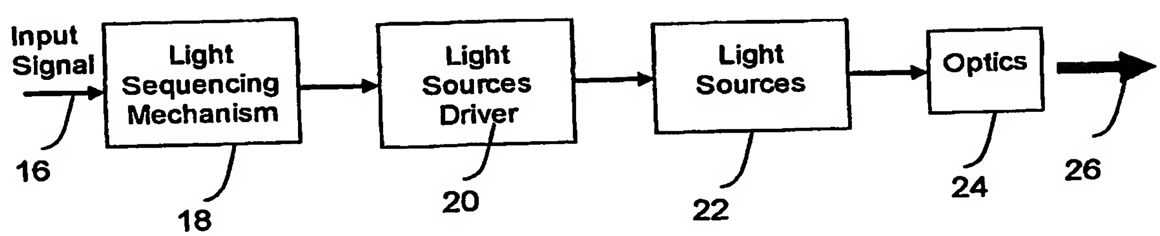


**Figure 3**

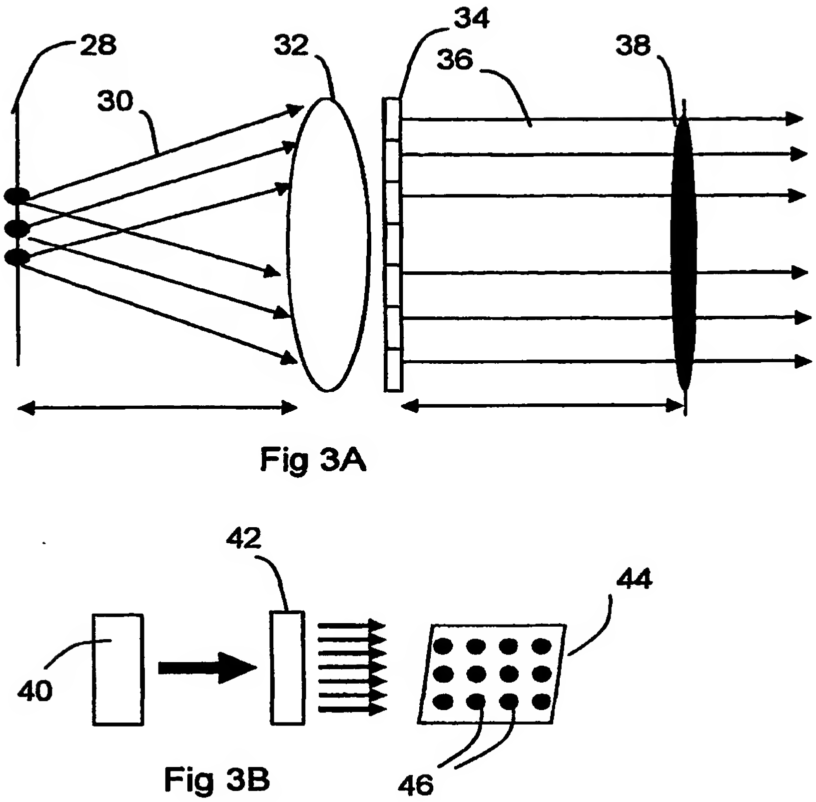



Fig 3A

Fig 3B

**Figure 4**

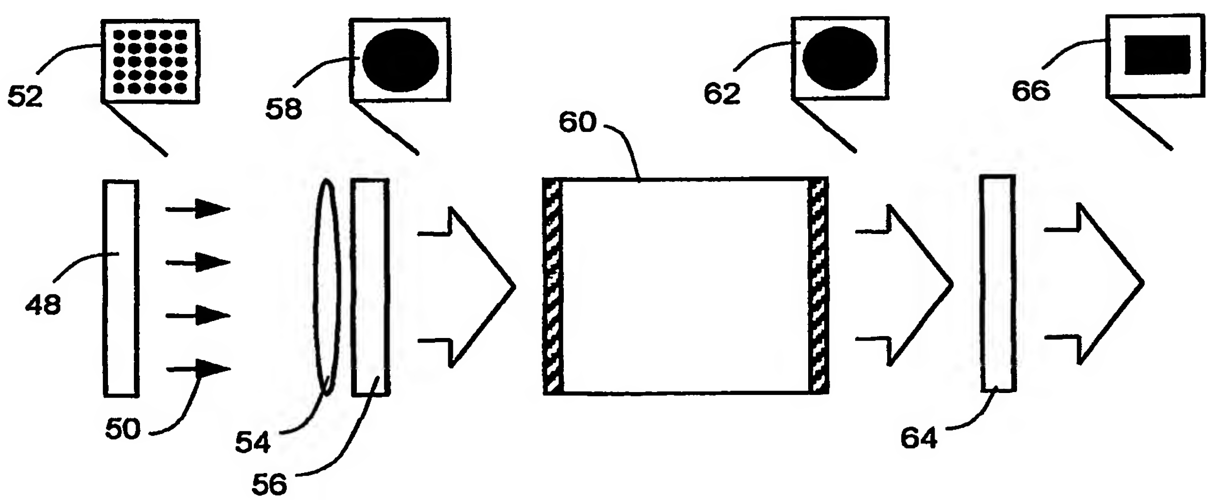


**Figure 5**

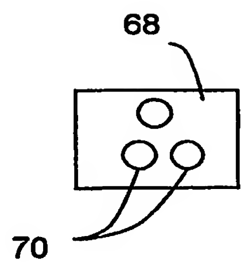



**Figure 6**

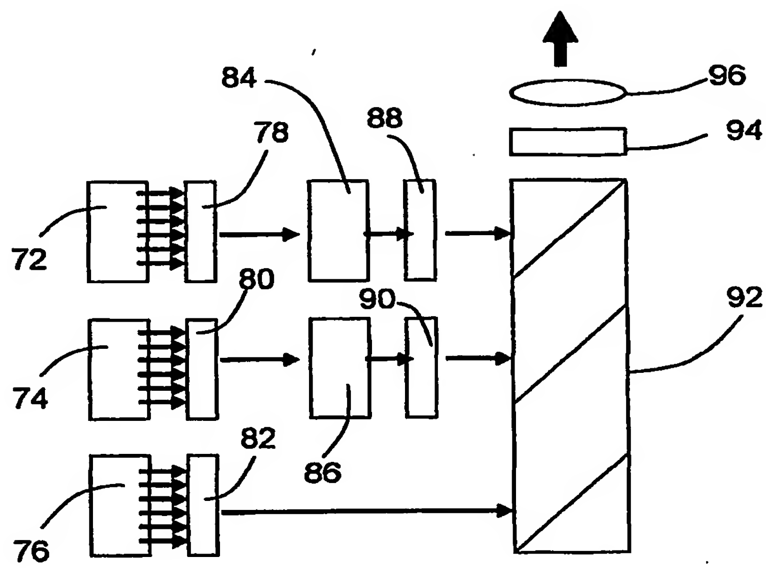


**Figure 7**

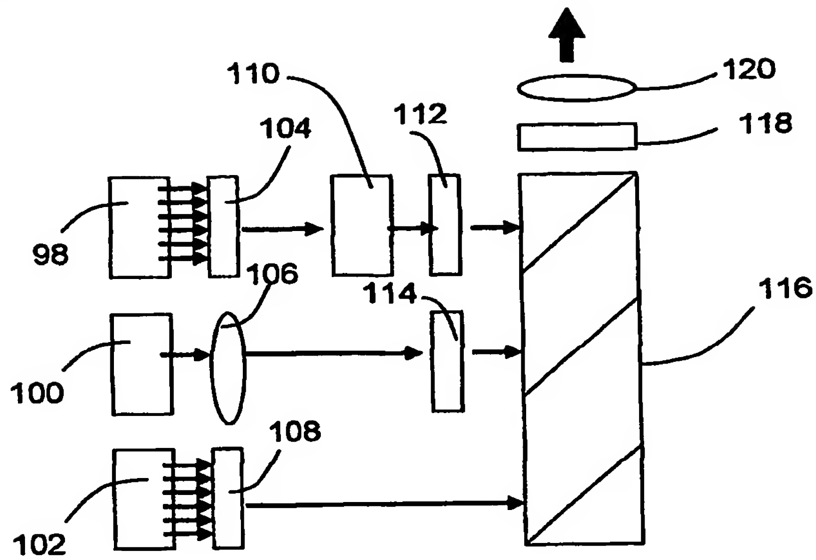



**Figure 8**

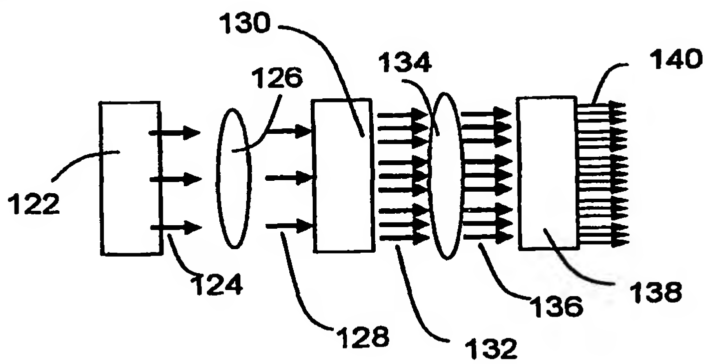



Fig 8A

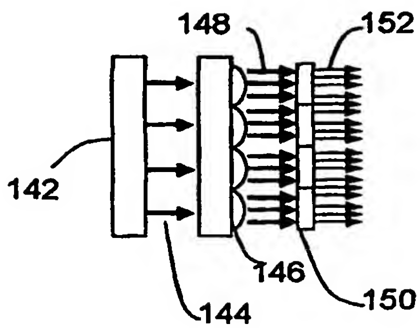



Fig 8B

**Figure 9**

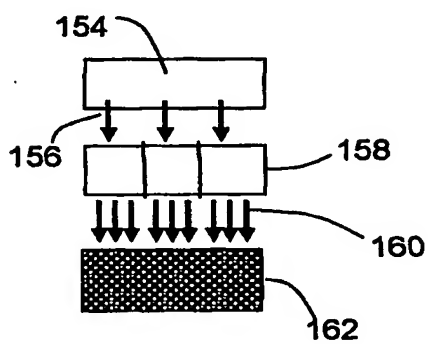


**Figure 10**

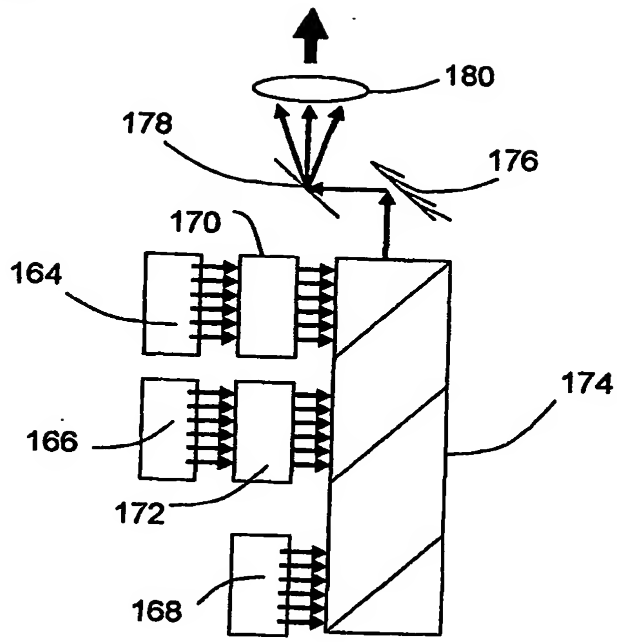
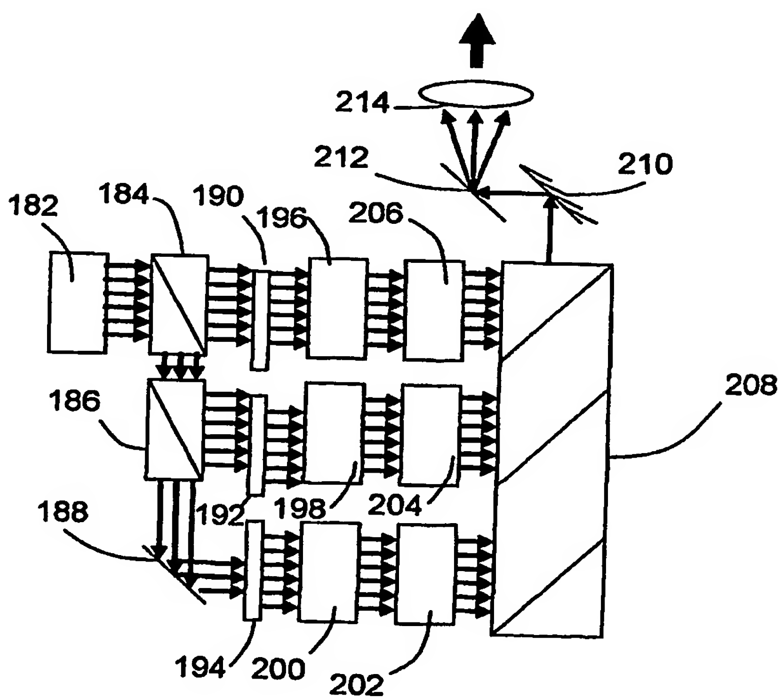



**Figure 11**



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